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Title:	Qualitative comparison of Benchtop (415KeV) and Synchrotron (215KeV) X-rays and 800 MeV protons for tomography of 5mm diameter Urania cylinders
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Form 836 (7/06)

Qualitative comparison of Benchtop (415KeV) and Synchrotron (215KeV) X-rays and 800 MeV protons for tomography of 5mm diameter Urania cylinders

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Two surrogate nuclear fuel types were examined with three radiographic probes. The samples were rods (a few cm long) of urania and thoria-ceria that were 5mm and 10mm in diameter respectively. Spatial and density heterogeneities were introduced with inclusions during sintering and by altering the sintering conditions during powder consolidation. Three radiographic tools were used; benchtop (425 KeV) X-rays, synchrotron (225KeV) X-rays and 800 MeV protons. Tomographic reconstructions were produced. The spatial and density resolutions achieved with the different techniques are compared as well as the potential for their improvement. The potential application of the different techniques to highly radioactive samples will also be considered.

Qualitative comparison of Benchtop (415KeV) and Synchrotron (215KeV) X-rays and 800 MeV protons for tomography of 5mm diameter Urania cylinders

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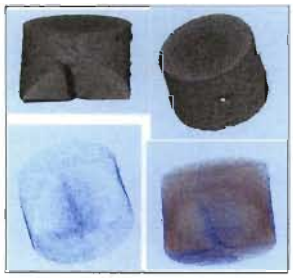
Sample preparation D. Byler UO2 C.F. Chen (Thoria – Ceria)

LANL / Benchtop J.F. Hunter , D. Brown

LANL / PRAd measurements G. Hogan , K. Kwiatkowski, F. G. Mariam, F. Merrill, C. L. Morris, and A Saunders

APS for SXR measurements Jeff Terry, Jeremy Kropf, Dan Olive

[Outline]
Context
Why
Radiography other
Tomographic reconstruction
Sample Fabrication
Three techniques
Comparison of salient features
Wedges
Density
Resoultion estimates
Optimization opportunities
Conclusions
[Thoria-Ceria]



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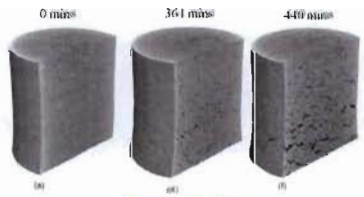
Context

CMIME Center for Material at irradiation and Mechanical Extremes

CASL Consortium for Advanced Simulation of LWRs

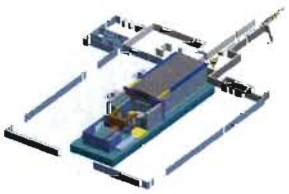
Materials Modeling and Simulation capabilities are critical to addressing challenge problems

- Assess materials performance under conditions of higher burnup, higher temperature, and higher cladding dose
- Optimize design of new materials



Creep of CuZn
Diameter is 1mm, ~1μm resolution, minutes

MTS will be a fast spectrum fuel and materials irradiation testing facility



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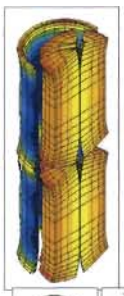
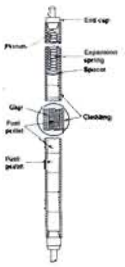
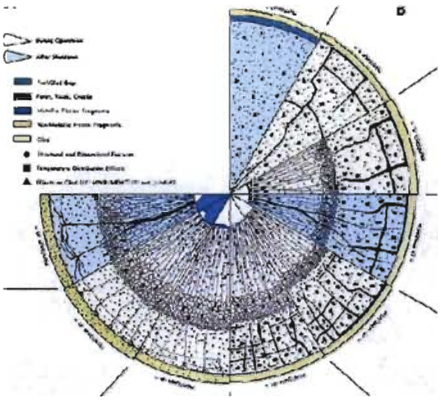
Why

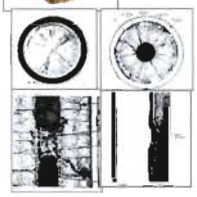
1) Finite element predictions of stress in cladding are predicated on assumptions about temperature distributions in the fuel, swelling and deformation mechanisms in the cladding





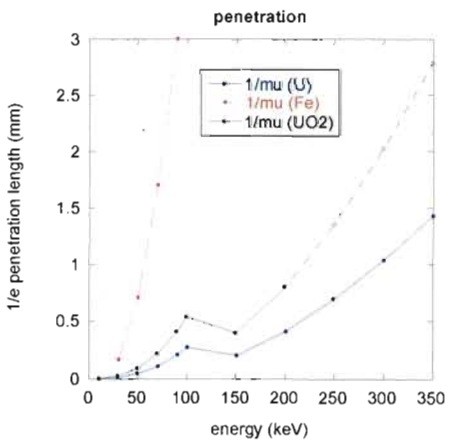


2) Fuel performance is controlled by oxidation, corrosion, fuel clad interactions, localized melting, restructuring and chemistry.



Urania absorption f energy

Increasing X-Ray Energy Allows Penetration of Even UO2



Sample Preparation :- Cylinders Urania UO_2 ~ 5mm long , ~ 4.6 mm diameter

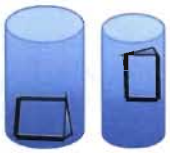
Variable Density

% Max theoretical density

Pellet #	Mass (g)	Density (g/cc)	%TD
P-dUO-08-571	0.88745	10.32	~ 94
P-dUO-08-577	0.86811	10.11	~ 92
P-dUO-08-576	0.87310	9.74	~ 88
P-dUO-09-069	0.8282	8.57	~ 78
P-dUO-09-068	0.4916	5.32	~ 48

Tungsten inclusions

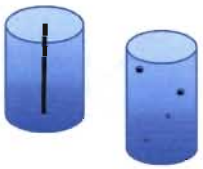
Wedges, Wires, Particles



Pellet #	Comments
P-dUO-09-071	Tungsten wedge in radial direction size from 230 to 24µm taper
P-dUO-09-070	Tungsten wedge in longitudinal direction size from 319 to 49µm taper
P-dUO-09-073	Tungsten wires in longitudinal direction sizes 75, 100, 200µm x ~3-4mm length
P-dUO-09-075	Tungsten wires in transverse direction sizes 75, 100, 200µm x 3-4 mm length
P-dUO-09-072	Tungsten particles dispersed in sizes from 75 to 200µm
P-dUO-09-079	Tungsten wire pieces cut to approximately same length as diameter in 75, 100, and 200µm sizes

PMMA Wires

5 of Wires and spheres



Pell #	Comments
P-dUO-09-077	Line Voids produced by Fishing line 210µm diameter in center in longitudinal direction
P-dUO-09-080	Ideally spherical voids produced by PMMA polymers
P-dUO-09-076	Line Voids produced by Fishing line 210, 270, 380µm diameters in transverse direction (radially)
P-dUO-09-078	Line Voids produced by Fishing line 210, 270, 380µm diameters in longitudinal direction

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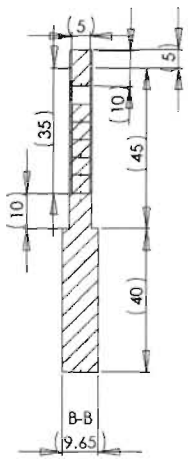
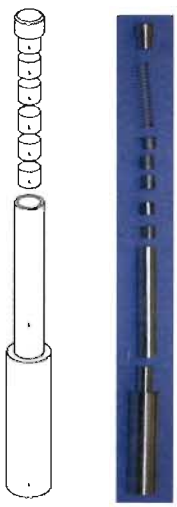
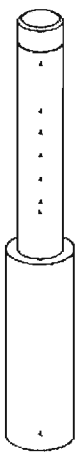
Assembled into cans







(mm)

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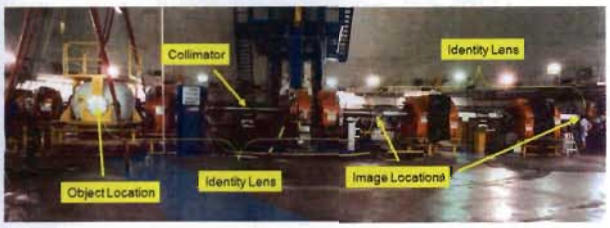
Experimental Setup



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Details

	BENCHTOP X-Ray	Protons	Synchrotron X-Ray
Energy	415 KeV	800 MeV	215 KeV
Sample to Detector	~ 2 m	~ 8 m	
Source to Sample	~ 2 m		~ 27 m
Detector Pixel	~ 130 μm	~ "25 μm" with X3 mag. (~ 70 μm)	~ 6 μm
Source	Phillips 450 adjustable tube	LANSCE	ID-10 Advanced Photon Source
Filter	2mm Sn, 0.5mm Cu		0.8mm Al, 0.83mm Cu, 2.0mm Sn, 0.4mm Ta, 4.8mm Pb
Frames per second	20 Avg, 0.5fps, 150 views		
Collimation	Tapered tungsten Collimator against tube coffin + rectangular leaf collimator 11 inches from the part.		
Spot Size	~ 1 mm		
Misc.			Cadmium tungstate detector 5 10 e4 photons/s / 4pi

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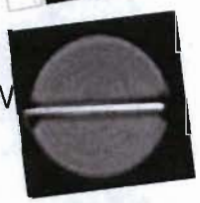
Urania Pin 1 Pellet 71 W Wedge
(Radial orientation 230 to 24 um taper)

P-dUO-09-071

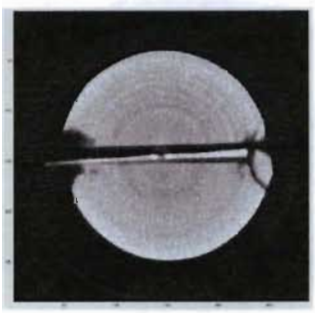
450 KeV 1 / 71 / W wedge

Prad 1 / 71 / W



SXR 215 Kev 1 / 71 / W wedge

SXR (Top) 1 / 71 / W wedge



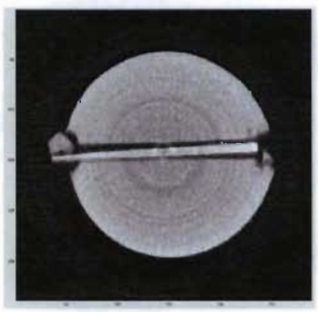
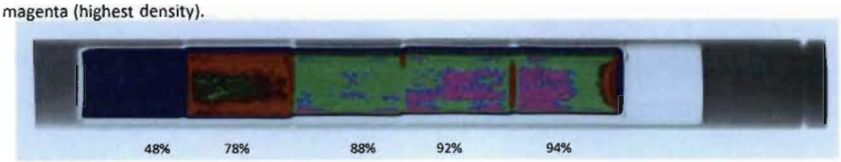


Figure 17 – Comparison between slices with the 450 keV (bottom) and APS 4x4 binned data. Note that the thickness of the slices means the Urania piece is visible in both 450 keV slices while it is no longer visible in the thinner APS data.

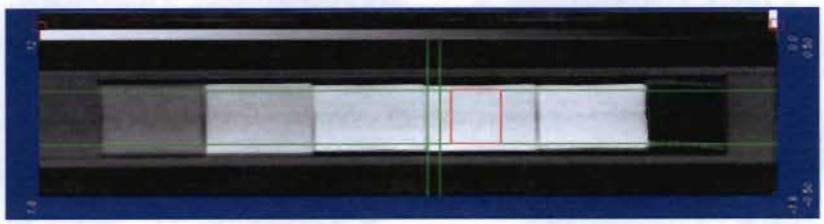
Density Characterizations

450 2 / 571 – 068 / 94% to 48%

Figure - Color coded cross-section of pellet-2. Density progresses as blue (lowest density) -> red -> green -> magenta (highest density).

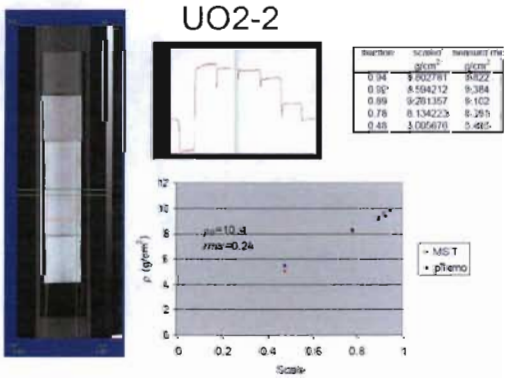


Prad 800 2 / 5 of / Density (radiograph?)



PRAD Density estimates

Table 3 – Density and measured attenuation for Pin 2 pellets



	Density	Attenuation
Pellet 1	94.18	1.256
Pellet 2	92.12	1.244
Pellet 3	88.83	1.2282
Pellet 4	78.23	1.1156
Pellet 5	48.56	0.7668

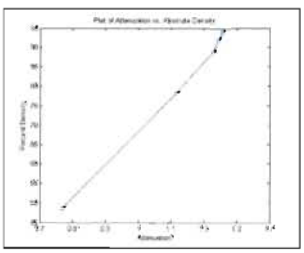


Figure - Plot of attenuation vs. density for pin 2.

Potential for variable density measurements .... SXR 215
1 / 71 / Wedge

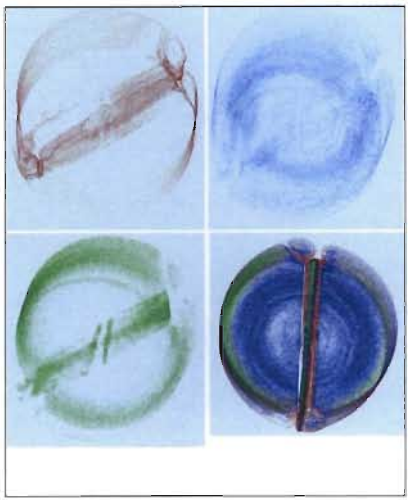


Figure – Transparent 3D renderings of pin 71 with only partial segments shown. Red is low attenuation, blue is medium attenuation, green is high attenuation and the final image shows the three combined.

Line Voids

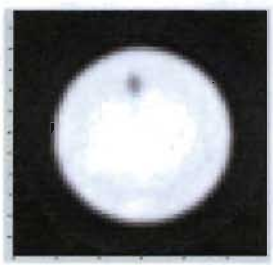
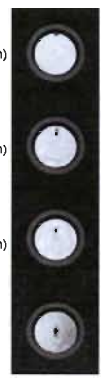


Figure – 3D and cross-section through Pin 3 pellet 2.



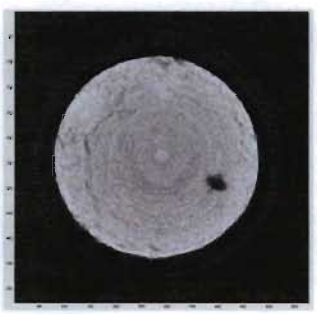


Figure – Reconstruction of approximately* the same slice with 2x2 binning (11.69μ) APS system and 450keV (127μ) LANL system. Note that images are rotated ~110 degrees relative to each other. * Approximate because the APS slice is more than a factor 10 thinner.

450 KeV 3 / 78 / Voids

Prad 3 / 78 / Voids ?

SXr 215 KeV 3 / 78 / Void

SXR 215 keV 3 / 78 / Void

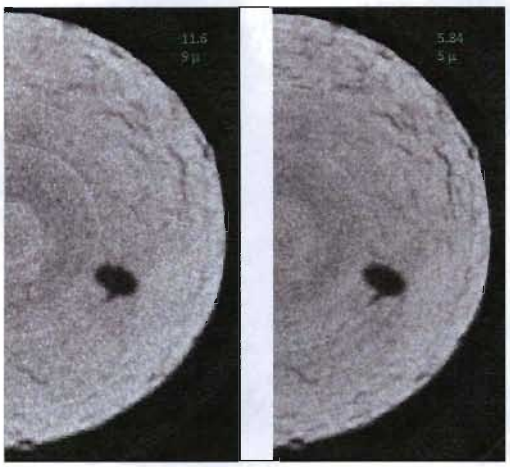


Figure – Side by side comparison of full resolution (5.845μ) and 2x2 (11.69μ) reconstructions in sample 78. Although slightly noisier the full resolution image is notably sharper.

Open Questions

- Field of View (PRad cf SXR cf Bremh)
- Detector resolution
- Radiation sensitivity
- Viability on Thicker specimens
- Optimal energy

Conclusions

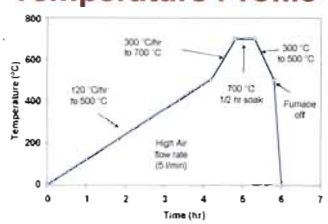
- Smallest features seen here approx 5 um
- Density determination by PRAd was within 1%
- SXR demonstrated best resolution
- All three techniques would benefit from improved detectors
- Field of view was largest for PRAd
- All measurements completed in less than a few minutes
- View through cladding not a problem

Thoria-Ceria

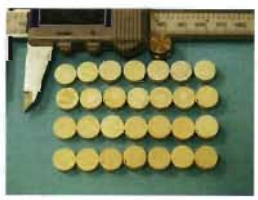
CeO_2 Raw Powder

ThO_2 Raw Powder

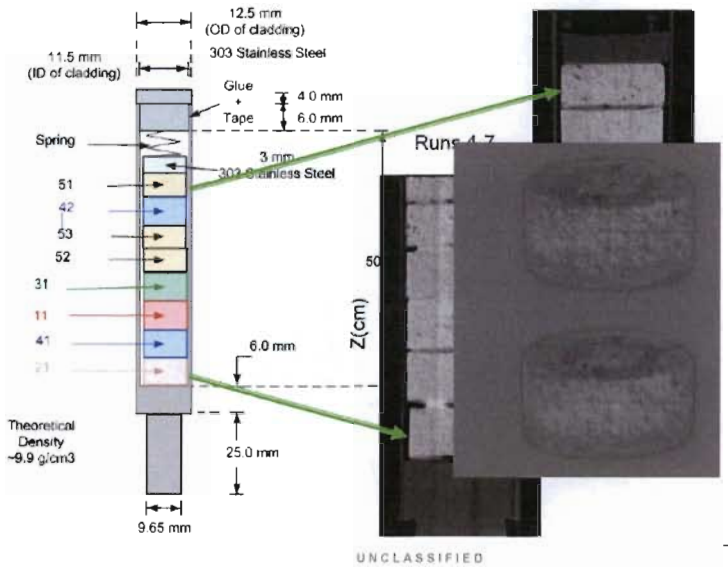
Binder Burn-out Temperature Profile



Sintered pellets



Thoria -Ceria



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